Adaptive CFAR Performance Prediction in an Uncertain Environment

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LONG-TERM GOALS

The long-term goal of this task is to more accurately predict passive sonar detection performance when both the signal wavefront and noise field directionality are uncertain.

OBJECTIVES

The objective is to bound the behavior of actual sonars by using the performance of optimal constant false alarm rate (CFAR) detection statistics, such as the adaptive matched subspace detector (AMSD), in the presence of realistic ocean environmental uncertainty and limited noise-field training data.

APPROACH

The well-known sonar equation (SE) is the classical method of predicting passive sonar performance. The SE is derived assuming both the signal wavefront and noise field directionality are known exactly. As a consequence, the SE depends only on post-detection signal-to-noise ratio (SNR). Detection performance calculations in uncertain environments with known noise field directionality has been previously addressed using Gaussian signal wavefront models and are also being developed by Nolte using Bayesian priors on environmental variables. In our work, we evaluate detection performance when both the signal wavefront and noise field are unknown. This is the so-called adaptive detection problem where, in addition to SNR, detection performance is limited by both signal wavefront uncertainty and the amount of training data available to estimate the noise covariance matrix. We use the adaptive subspace detection framework developed in (Kraut, et.al. [1]) for an M sensor array with a p dimensional signal subspace which increases with environmental uncertainty. The value of p is found from the signal wavefront covariance matrix computed over an ensemble of environmental realizations. Adaptive detection, in this framework, assumes that a set of K "signal-free" training data vectors are available to estimate the noise covariance matrix. Strictly speaking, this is not true in the passive sonar problem where the signal may be in the training data. However, the performance of optimal adaptive detectors considered here can reasonably be expected to bound the performance of the more realistic, but thus far theoretically intractable, situation.

WORK COMPLETED

The evaluation of detection performance was performed using the generalized likelihood-ratio test (GLRT) for this problem, which is an extension of the Kelly GLRT to the problem of detecting multi-rank signals in noise with unknown covariance matrix. In lieu of complete receiver operating

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14. ABSTRACT

The long-term goal of this task is to more accurately predict passive sonar detection performance when both the signal wavefront and noise field directionality are uncertain.

15. SUBJECT TERMS

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characteristics, detection performance can be expressed by using a figure of merit (FOM) defined as the input SNR required by the optimal detector to achieve a 50% detection probably at specified probability of false alarm. Using familiar components of the sonar equation, the FOM = SL-NL+AG-DT, where SL and NL are the source and noise levels, AG is array gain, and DT is detection threshold, all expressed in dB. Unlike in the classical SE, however, in work completed this year we have computed DT using recently derived statistics of the GLRT for the problem where the ocean is uncertain and the noise covariance is unknown. This new DT depends on both the dimension of the signal subspace, p, and the number of training snapshots, K, available to estimate the noise covariance. Moreover, since different environments result in different array gains as a function of hypothesized target direction, we have computed the minimum and maximum AG for a given range of environmental conditions. Finally, in order to illustrate the use of our performance prediction, we have translated FOM into minimum and maximum "range-of-the-day" estimates using a realistic noise field directionality example and a simplified propagation model with uncertain environmental parameters.

RESULTS

To study the relative importance of signal wavefront uncertainty versus limited training data for noise field directionality estimation, we have computed the probability of detection (PD) versus post-beamformer SNR as a function of both signal rank, p, and number of snapshots, K, for a $M=30$ horizontal sensor array.
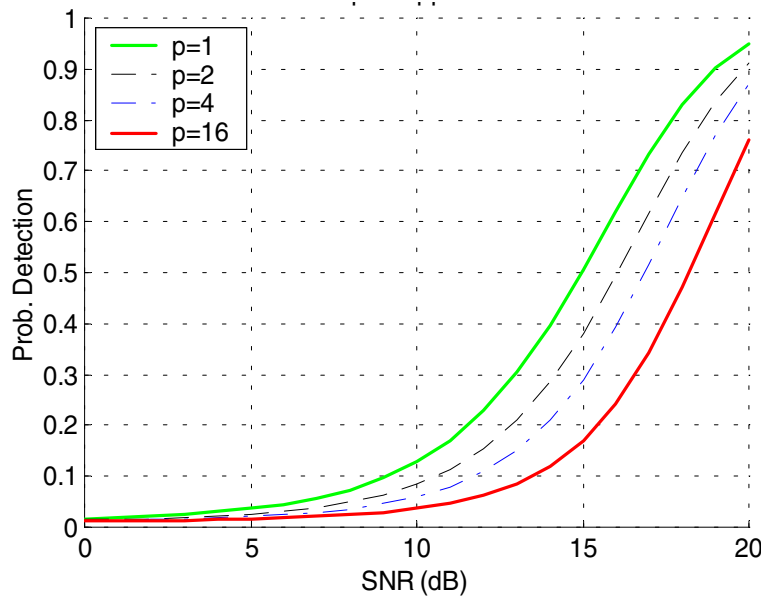

Figure 1: PD vs. SNR for Different Levels of Environmental Uncertainty (p)

Figure 1 illustrates the degradation in PD with increasing signal wavefront rank, p, for $K=35$ snapshots. Figure 2 indicates the performance loss in PD incurred when using fewer training snapshots when the environment is known.
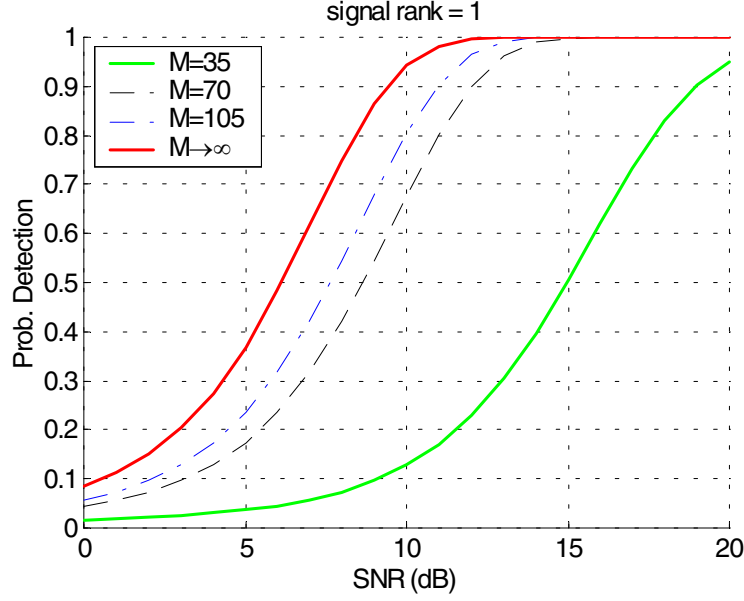
Figure 2: PD vs. SNR with Different Amounts of Training Data (K)

Comparison of Figures 1 and 2 suggest that the detection performance loss due to limited training data can be more significant than losses due to increasing signal wavefront subspace rank, especially in highly dynamic environments. Although these curves are exact for the model considered, we have also derived a rule-of-thumb approximation for the new $FOM_{new} = SL-NL+AG-DT_o-5log(p)+10log(1-M/K)$ where DT_o is the detection index assuming a known ocean and noise covariance. Note that the new FOM includes both signal rank and number of training data snapshots.

To illustrate the use of the new FOM for an uncertain environment with realistic noise inhomogeneity, we computed the minimum and maximum FOM as a function of bearing using noise field measurements from a real horizontal towed line array in shallow water. We used a simple propagation model to translate the FOM to min./max."range-of-the-day" which is plotted in Figure 3. The range-of-the-day predictions shown in Figure 3 depend on both the bearing dependent SNR and signal wavefront uncertainty. The results indicate that not only does environmental uncertainty result in performance losses but also in a significant loss in performance prediction ability as the look direction goes further off broadside. In practice, these best-case/worst-case FOM predictions could be updated as new estimates of the environmental model and noise field directionality become available.
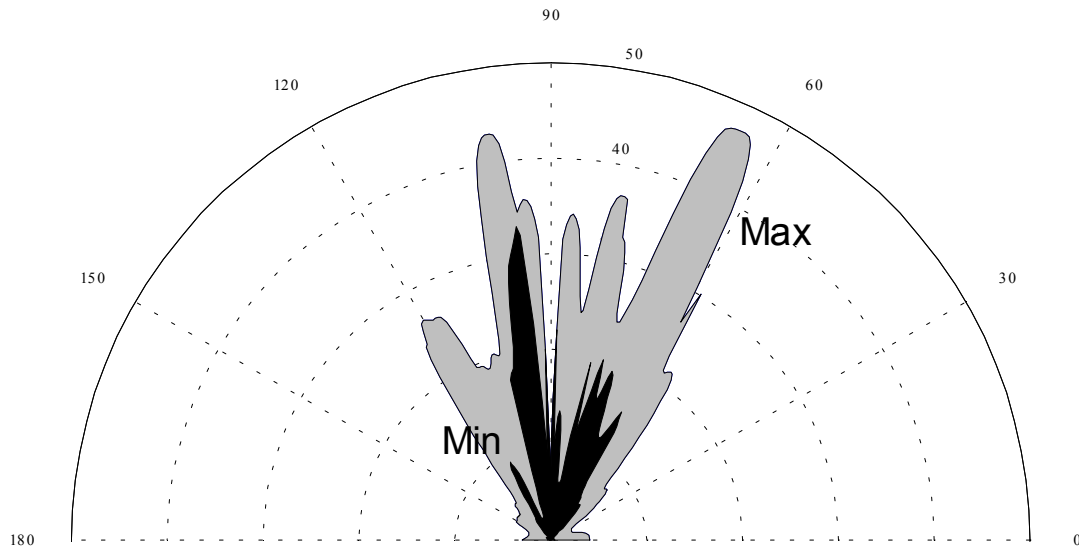
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Figure 3: Min/Max Range-of-the-Day Prediction vs. Bearing

IMPACT/APPLICATIONS

This work could impact the development of tactical decision aids for passive sonar which incorporate environmental uncertainty and limited training data in their detection performance predictions.

REFERENCES

1. Kraut, S., Scharf, L.L. and McWhorter, L.T. "Adaptive subspace detectors", *IEEE Trans. on Signal Processing*, vol. 49, no. 1, January 2001.